Farm Animal Manure is an Important Sustainable Renewable Energy Resource

Dr. John Sheffield.
Director for Energy Technology Programs, Oak Ridge National Laboratory, PO Box 2008, Oak Ridge, TN 37831-6248.
Director of the Joint Institute for Energy and Environment at the University of Tennessee.
Tel: 865-574-5510, 865-974-9224.
Fax: 865-576-6118.
E-mail: sheffieldj@ornl.gov

Abstract

Farms for raising cattle, poultry, and swine are very important to feeding this country and other parts of the world. However, they can suffer from severe environmental problems. In the United States alone at least a billion tons of manure, wet weight, are generated annually. Run-off and emissions from these farms and the fields that provide feed for them - fertilizers, pesticides, pathogens, antibiotics, and hormones - can pollute the water and air The manure contributes significantly to greenhouse gas emissions. Methane emissions for the U.S. alone (about 10% of the manure) are estimated to be 2.76 million tonnes for 1996.

Fortunately, technological solutions, cleverly applied, can offer additional benefits to the farmers to offset the costs of pollution control. In fact, given the wealth of technological opportunities to do better it might be possible to become more profitable. The manure is commonly used as a fertilizer, but it also represent a large, generally untapped, source of energy and can be utilized as a feedstock for both energy and other products.

It is estimated that the world's farm livestock and poultry includes about 1 billion cattle, 0.8 billion pigs, 0.9 billion sheep and goats and, on average, 8 billion chickens (broilers and layers). A rough estimate of total dry weight for the world's farm animal manure in 1997 is 1.7 billion tonnes. The energy content of dry manure is in the range 12 to 18 GJ per tonne, about half that of coal. If half of this amount of manure were collected it would have an energy content of about 12 EJ/year (300 million tonnes of oil equivalent per year), or about 10% of present world oil use. The use of anaerobic digestion in a contained system has the additional advantages of a significant reduction in pathogen levels in the remaining manure; important to its safe application as a fertilizer.

The best solutions to the problems will require an understanding of the integrated picture. The areas involved include agriculture, biomass energy, biology & medicine, biotechnology, separations sciences, chemical engineering, economics, energy end-use and production technologies, computer modeling, environmental sciences, hydrology, sensors (standard and special) integrated with data collection and analysis capabilities, and the capability of integrating all the knowledge into the design of more effective systems.

In this paper, visions of systems of the future are discussed, highlighting the opportunities to benefit from advances and contribute to sustainable energy and reduced greenhouse gas emissions.

1. Introduction

The livestock and poultry industry is a vitally important contributor to the economy and security of the United States, producing low-cost eggs, meat, and milk. An inevitable by-product of this industry is manure. Manure is a valuable resource for nutrients, has soil enhancement properties and, separately, may be used for energy. The effective recycling of this resource is essential.

As the industry has evolved, the production of animal food products and manure has become more concentrated and, in many places, separated from the areas that can handle the manure using the traditional approach of land application. Further, tightening environmental regulations to protect water resources are decreasing the profitability of producers under the present product marketing system. A lack of a comprehensive set of policies, regulations, penalties and incentives, compounds the problems of the industry. The problems are aggravated further by public concerns and misconceptions about producers and about the industry in general.

There are social aspects of the business, environmental and regional wellbeing and regional dimensions of the operation that make this an area for involvement of federal, state and local authorities. In addition, all of the stakeholders - the whole livestock industry from fertilizer and feed and equipment manufacturer (i.e., farm supplier), to farmer and integrator, wholesalers and retailers, transporters, the environmental community, bankers - need to be involved in finding beneficial solutions that can enhance both the business and the environment.

Unfortunately, the farms and manure can be a source of pollution. Run-off from farms contributions to water pollution include nitrogen, phosphorus, potassium, and sodium. In addition, there can be releases of the antibiotics and hormones given to the animals, and pathogens from the animal manure must be minimized. Air pollution includes ammonia, hydrogen sulfide, mercaptan, dust, and methane. Attention on the waste issues is seen in the regulatory trends at the federal and state level. However, state and local regulations vary and there is not a level playing field.

An exciting vision for this important area of the economy is of “Environmentally sustainable food animal operations that are, safe, socially acceptable, and profitable”. In achieving this vision, it is important for the producers to be able to transfer the real cost of meeting environmental expectations to the consumers.

Fortunately, there are a number of complementary routes to achieving this vision:
• A more systematic approach to policy, regulation, penalties and incentives;

- Consumers paying a realistic prices for the products and supporting government programs that ensure the optimum use of the manure;
- An improved nutrient recycling system;
- Voluntary programs for environmental certification coupled with environmental labeling and premium prices;
- Enhanced assistance programs tailored to meet the needs of farmers and for public education; and an important consideration for this report of
- **The utilization of value-added, bio-solid and bio-energy products;**

2. Farms of the Future

Vision

“Sustainable agriculture is an integrated system of plant and animal production practices that will, over the long term:

- Satisfy human food, fiber, and speciality chemicals needs;
- Enhance environmental quality and the natural resource base;
- Make efficient use of non-renewable resources;
- Sustain economic viability of farm operations; and
- Enhance the quality of life for farmers, farm families, and society.”

Maximizing the benefits from the use of manure will be an important aspect of “Farms of the Future”. It will require policies and regulations, combined with technologies that provide a win-win-win situation for all the players. The manure is a resource as a fertilizer, as a soil amendment, and as a source of chemicals and energy. The beneficial balance of such products will vary widely from case to case. Therefore, a wide range of solutions to manure use will be used to meet the vision of “Farms of the Future).

- There will be integrated farming practices that achieve a closed loop system with the manure recycled in e.g., some combination of other crops, aquaculture, and energy use. Optimization of the entire production system rather than maximization of any one of its components will be achieved. If this is not achievable at a farm scale, then local or regional closed-loop systems i.e., “agriplexes’ are an attractive possibilty.

- From the fertilizer/chemicals perspective, methods will have been developed for concentrating key nutrients to economically transport them back to the areas where animal feeds are produced, and/or use them as feedstocks for other chemical processes.

From a closed-loop recycling perspective, including the fertilizer manufacturers in the process is desirable.

- Proper application of liquid slurry and solid manure will be accomplished through comprehensive nutrient and land management, including appropriate application, filter strips, riparian buffers, and constructed wetlands.

- A high percentage of the energy in the manure will be recovered by firing or co-firing the manure with coal or by extracting methane and using it to produce electricity and process heat for use in the livestock operation, for sale, or for making ancillary products, e.g., in greenhouses. Solar energy may be used to maintain digester temperature in cold climates. The cooperation of the utilities is important in encouraging the use of this distributed electricity generation and process heat, through net metering, support of operations and possibly through the operation of larger regional digesters. Incentives for the utilities can include having subsidies, emissions credits and green labeling.

- Combining livestock production with some other operation will lead to benefits for both operations, e.g., coupling to ethanol production, coupling to biomass energy crops, and coupling with other waste streams - agricultural, forestry-derived, industrial and municipal – for co-firing or as mixed feedstocks for chemical production.

In the vision such solutions will be readily usable on the farm, reliable, and a support infrastructure must exist to maintain the equipment. The performance of each system will be well established so that sound business decisions can be made on investment in them. Simplicity, per se, is not the primary issue. Modern PCs are very complex and involve sophisticated electronics, but there is no requirement for the user to understand the details of how they work. They are, generally, user-friendly, provide good value for the investment and, if something goes wrong, there are service organizations available. New farm equipment and production processes must fit in the same mold.

Economics

It will be necessary to factor in the total costs and benefits (including the waste streams and opportunity costs) and to be clear about who should pay. Demonstration projects of new technology are needed to qualify new, beneficial approaches to improving the manure handling. Some of these demonstrations should be on farms. Because it is unlikely that the farmer will benefit from sales of the equipment demonstrated, the costs should be born by the manufacturers who will profit. The farmer cannot afford to be a test-bed for new equipment, and a buy-down of the first phase costs is desirable, as has been done in the introduction of a number of green technologies.

Green pricing and marketing programs, such as voluntary premiums for sustainably priced products, will be helpful – recycled paper, green power, bottled water. A new marketing slogan might be “Green Eggs and Ham”.

Utility Roles

The deregulation of the electric utility industry is changing traditional utility roles. There is a competition between Independent Power Producers (IPPs), ESCOs and new entities. There are new opportunities for customer service and retention. The short-term outlook is about 5 years. Utility roles include, energy purchases and sales, greenhouse gas broker, power distribution/ supplier wheeling, project developer/operator, customer service provider and business partner and consultant. Project financing options include, build-own-operate, finance, and lease. Important considerations include; general economic development, equitable customer treatment, energy management, and ensuring the safety and reliability of the system. Policy and regulatory considerations include; net metering, renewable portfolios, green energy premiums, greenhouse gas credits, and waste regulations (public policy influence); deregulation, state and federal variations and uncertainties; standardized interconnect standards, wheeling, power purchase limitations, stranded costs, existing power purchase agreements, tax credits (REPI, production, investment), and permit flexibility in fuel types.

Decision Tools

Decision tools, for assessing large-scale manure benefaction systems are needed (some exist). These would assist decision-makers in optimizing processing options, environmental goals, markets, and profitability. Existing tools should be assessed in regard to feed-back loops, early or late handling of manure, and processing options and decisions. These would be able to optimize particular combinations of manure quality, technologies, environmental goals, markets and profits. Existing tools should be assessed for their completeness and accuracy, so that desirable upgrades may be identified and developed.

Coordinated Support

State agricultural, environmental, and energy agencies can help by working with each other, and with agencies in other states to promote improved management practices. Good communications with the livestock business and its suppliers, universities, laboratories, and federal agencies are clearly important to optimizing opportunities.

3. Energy Production

Opportunities

It is estimated that the world's farm livestock and poultry includes about 1 billion cattle, 0.8 billion pigs, 0.9 billion sheep and goats and, on average, 8 billion chickens (broilers and layers). A rough estimate of total dry weight for the world's farm animal manure in 1997 is 1.7 billion tonnes. The energy content of dry manure is in the range 12 to 18 GJ per tonne, about half that of coal. If half of this amount of manure were collected it would have an energy content of about 12 EJ/year (300 million tonnes of oil equivalent per year), or about 10% of present world oil use.

For the United States, the equivalent numbers are about 250 million tonnes dry weight of manure per year, and half the energy would amount to around 2 EJ/year (45 million tonnes of oil equivalent per year).

Systems to capture both the nutrient and energy components of manure represent an opportunity to add value to livestock operations. Systems to reduce the amount of water can increase the value and options for nutrient use. Digestion at high enough temperature (notably above 50 ^{o}C), can reduce the levels of pathogens substantially. In cold conditions, it is sometimes difficult to sustain adequate temperatures in certain kinds of digester. Solar heating can be used to boost the temperature. Dry manure may be used for composting, direct application to the land, as a fertilizer and for soil enhancement, and for combustion e.g., co-firing with coal.

Energy Production

Energy may be generated directly by combustion of the solids in manure, to provide either process heat or electricity. In the latter case the solids may be co-fired with other wastes of fossil fuels e.g., coal.

When methane is produced by anaerobic digestion, it may be flared, the benefit being a reduction in both odors and greenhouse gas emissions (methane has a 22 times stronger greenhouse gas impact than carbon dioxide). More usefully, it may be used to make electricity and/or process heat. The quality of the gas mixture from digestion is not as good as pure methane and the typical efficiency of, presently used, electricity generators is about 20 to 25%. Opportunities to improve efficiency should be possible with Sterling engines, microturbines designed for the biogas (about 30%), and from the use of fuel cells (40% or more efficiency). The availability of lower cost, more effective gas separations equipment could improve the overall efficiency of the system. Liquid fuels might be produced from the methane or more directly from the manure.

Utility Factors

Interconnect standards, uniform permit requirements, and net metering are important aspects of the production, use, and sale of the locally produced electricity. The availability of greenhouse gas credits, Renewable Energy Production Credit (REPI), production tax credits, and green labeling would help in encouraging this distributed electricity generation. Federal and state authorities can help by supporting the research, development, and demonstration of advanced technologies, by providing incentives for their use, by providing a stable regulatory environment, by thoughtful zoning, and by assisting in information dissemination and public education. The shared funding of nutrient management programs, such as the Environmental Quality Incentives Program (EQUIP) and Best Management Practices (BMP's) etc, is encouraged.

4. Energy Technologies

There are a number of approaches to converting the energy in manure to electricity. Heat recovery is an important element of each approach.

Fuel Cells

There are numerous types of fuel cell, but the ones most appropriate to farm application are those that operate at high enough temperature to produce process heat – solid oxide, and phosphoric acid cellsThey are well optimized to operate in the kiloWatt to megaWatt range of power. The basic fuel may be hydrogen, methanol, natural gas, diesel fuel, and biogas. High temperature fuel cells are more compatible with the low-grade gas from bio-digestion. As a source of combined heat and power, they can be very efficient 60% or more, with 40% or more electricity production efficiency. Issues include: their present cost, lack of a large data base on reliability, perceptions of safety, and their vulnerability to poisoning e.g., by H_2S.

Microturbines

Recent developments of microturbines have led to relatively efficient (about 30%) devices at low power 10's of kiloWatts. Such are cost-competitive, have low maintenance, fuel flexibility, and can provide combined heat and power. They have the potential for higher electrical conversion efficiency with improvements, and have low emissions. There are a number of developers. Issues include the need from gas cleaning and scrubbing, corrosion from components of biogas, and the biogas must be compressed. They are, generally, not optimized for low BtU biogas, and need a heat exchanger for their waste heat. Their performance at lower load is worse, and they need power processing equipment including an inverter.

Conventional Turbines

Conventional turbines have load following capability, are fuel flexible, have low maintenance, and have a reliable track record. They operate in the 500 kW to 10 MW range and are oversized for most farms.

Internal Combustion engines

ICEs have a long track record and are cheap. Many sizes are available, and diesels are relatively efficient. It may be necessary to scrub the gas.

Fuel and Gas Storage

Fuel and gas storage is an important practical and economic issue. 12 to 24 hour storage is necessary for peak production management. The options are to compress and store or liquefy, or transport elsewhere.

Absorption Cooling

There are significant energy loads for cooling on dairy farms. New developments in gas fired technology (in DOE programs), though not yet cost-effective, hold promise for future applications on farms.

Instrumentation

There are needs for smart systems in many areas of the livestock industry. More accurate, reliable, and cost effective sensors and systems are required. System standardization, plug and play components, and analysis of the logic of system design are important. Measurements of nearly all components of manure and its products and uses would benefit the industry as discussed in numerous sections above. Modern low-cost, application specific integrated circuits

(ASICs) could dramatically improve understanding of the state of the systems and help in their optimized operations. Coupling to computer models will also play a big role.

Materials

High temperature, corrosion resistant materials are needed to deal with unpleasant components or products of manure such as hydrogen sulfide. The materials must be cost-effective for farms.

Gas Cleaning

Because some of the components of biogas are either corrosive (H_2S), or add no energy (H_2O, CO_2) value, or could have other value (NH_3), it is desirable to have separations and removal systems. Mesh screens for dust removal an catalytic conversion can also play a role.

Genetic Engineering

Genetic engineering could improve the biological conversion of manure to hydrogen, improve the quality and constituent balance of the feed, improve the ability of animals to better absorb some component of the feed (e.g., phosphorous), decrease H_2S, and increase the number of value-added products, for example methane to plastics.

5. Summary

The farm animal industry is a vitally important contributor to the economy and security of the United States, producing low-cost eggs, meat, and milk. An inevitable by-product of this industry is manure. Manure is a valuable resource for nutrients, has soil enhancement properties and, separately, may be used for energy. The effective recycling of this resource is essential.

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- Enhanced assistance programs tailored to meet the needs of farmers and for public education; and an important consideration for this report of
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“Summary of the Workshop on Opportunities to Improve and Benefit from the Management of Animal Waste”, JIEE Research Paper 99-01, May 1, 1999; and,

“Evaluation of Comprehensive Approaches Needed to Improve the Handling of Farm Animal Manure and Benefit the Environment and the Farming Industry”, JIEE Report 2000-07, July, 2000.